EXHIBIT 4

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Occupational Exposure to Asbestos: Population at Risk and Projected Mortality – 1980–2030

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Estimates have been made of the numbers of cancers that are projected to result from past exposures to asbestos in a number of occupations and industries. From 1940 through 1979, 27,500,000 individuals had potential asbestos exposure at work. Of these, 18,800,000 had exposure in excess of that equivalent to two months employment in primary manufacturing or as an insulator (> 2–3 f-yr/ml). 21,000,000 of the 27,500,000 and 14,100,000 of the 18,800,000 are estimated to have been alive on January 1, 1980.

It is further estimated that approximately 8,200 asbestos-related cancer deaths are now occurring annually. This will rise to about 9,700 annually by the year 2000. Thereafter, the mortality rate from past exposure will decrease, but still remain substantial for another three decades.

Key words: asbestos, occupational exposure, risk assessment, morality projections

INTRODUCTION

A large volume of research has been conducted on the adverse health effects of exposure to asbestos. However, relatively little is known about the magnitude of the population at risk to asbestos-related disease. A number of occupations and industries have been identified as involving substantial occupational exposure to asbestos, but no detailed evaluation has been made to quantify the number of persons whose employment experience has resulted in sufficient exposure to warrant characterizing them as at risk. This analysis is designed to provide an assessment of the extent and consequences of occupational asbestos exposure in the United States between 1940 and 1979.

The task of estimating the population at risk to asbestos-related disease is complicated by a number of factors:

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1. The precise number of persons occupationally exposed to asbestos at any given time is not known.

2. The level of exposure to asbestos necessary to increase the risk of incurring asbestos-related disease is only imperfectly known, estimates being complicated by the varying interactions of the two elements that go into "dose" (time and intensity).

3. The extent to which workers have changed occupations and/or industries from time to time so as to place them at risk to asbestos-related diseases (or to end such exposure) at any time in the past four decades is not known.

We have sought to overcome these obstacles by compiling the best available data concerning worker exposure to asbestos and the turnover of workers in the occupations and industries involved. The sources and methods used to estimate the population at risk are set forth below.

MATERIALS AND METHODS

Identification of Industries and Occupations at Risk

Workers are exposed to asbestos in a wide variety of industrial pursuits from mining and milling to primary manufacturing (producing manufactured goods from raw asbestos fibers) to secondary manufacturing (processing asbestos manufactured products to make other products) to consumer industries (utilizing a finished product containing asbestos without modification) [Daly et al, 1976].

Mining and milling. Fewer than 600 persons in the United States are employed in mining and milling asbestos [Meylan, 1978]. In view of the small number involved and the lack of information on employee turnover, we have excluded this industry from our estimates.

Primary manufacturing. The Asbestos Information Association has estimated that there are upwards of 3,000 discrete uses of asbestos. A selection of major asbestos products and their uses is presented in Table I. The primary manufacturing industries in which asbestos products are produced and which involve substantial asbestos exposure to production and maintenance employees are as follows:

Asbestos products industry (SIC 3292). The major products of this industry are friction products, asbestos-cement pipe and sheet, asbestos textiles, floor tiles, roofing felts, insulating materials, and other asbestos building materials.

Extensive data indicate that excessive fiber concentrations existed in the production of asbestos products during previous years. In a study of retirees from one of the largest asbestos products manufacturers, Henderson and Enterline [1979] categorized work exposures according to total dust concentration (as measured by a midget impinger) times period of employment. Using recently obtained data on the conversion between such particle counts and fiber concentrations, it is estimated that the average concentration to which the members of his cohort were exposed was 30 fibers/ml [Asbestos Information Association, 1979]. Similar concentrations were suggested for the work force exposure in a large United States asbestos products manufacturer studied by Nicholson et al [in press]. Here subjective data, consistent with company measurements of dust concentrations, suggested that the person-weighted average exposure was approximately 25 fibers/ml between 1945 and 1965. In two asbestos insulation manufacturing facilities in Port Allegany, Pennsylvania, and Tyler, Texas, aver-

TABLE I. Selected Asbestos Products and Their End Uses*

Floor tile	Gaskets and packings	Friction products	Paints, coatings and sealants	Asbestos-reinforced plastics	Asbestos cement pipe
Office floors Commercial floors Residence floors	Valve components Flange components Pump components Tank sealing components	Clutch/transmission components Brake components Industrial friction materials	Automotive/truck body coatings Roof coatings and patching compounds	Electric motor components Molded product compounds for high-strength/weight uses	Chemical process piping Water supply piping Conduits for electric wires

Asbestos textiles	Asbestos paper	Asbestos cement sheet
Packing components Gasket components Roofing materials Commercial/industrial dryer felts Heat/fire protective clothing Clutch/transmission components Electrical wire and pipe insulation Theater curtains and fireproof draperies	Gas vapor ducts for corrosive compounds Fireproof absorbent papers Table pads and heat protective mats Heat/fire protection components Molten glass handling equipment Insulation products Gasket components Underlayment for sheet flooring Electric wire insulation Filters for beverages Appliance insulation Roofing materials	Hoods, vents for corrosive chemicals Chemical tanks and vessel manufacturing Portable construction buildings Electrical switchboards and components Residential building materials Molten metal handling equipment Industrial building materials Fire protection Insulation products Small appliance components Electric motor components Laboratory furniture Cooling tower components

*Source: Daly et al, 1976.

age concentrations of 35 fibers/ml were measured by NIOSH between 1968 and 1971 [National Institute for Occupational Safety and Health, 1972].

These concentrations were characteristic of early exposure levels in manufacturing industries. In recent years, considerable efforts have been made to reduce fiber concentrations. During 1975, air levels of from 0.5 to 4.0 f/ml were found to characterize most primary manufacturing processes (see below). With appropriate engineering, even asbestos textile manufacturing can be controlled to levels below 1.5 f/ml [Lewinsohn et al, 1979].

Since substantial asbestos exposure is involved in all production and maintenance operations in this industry, we have included all production and maintenance workers in our estimates of the population at risk.

Gaskets, packing and sealing devices industry (SIC 3293). This industry encompasses products made of asbestos, leather, metal, and rubber. Prior to 1972, asbestos was the predominant raw material used. A change in the industry classification system in 1972 expanded the definition of this industry to include products made of leather, metal, and rubber [Office of Management and Budget, 1972]. Since approximately one half of the employees of the newly defined industry were employed in plants manufacturing asbestos products, we have included one half of the production and maintenance employees since 1972 in our estimates of the population at risk. For years prior to 1972, we counted all employees in the at-risk group.

Building paper and building board mills (SIC 2661). This industry covers the production of asbestos paper, asbestos board, and sheeting and various types of papers and insulating boards used in building construction. Since approximately one half of the employees in 1972 were employed in construction paper plants (where asbestos was the principal raw material), we have included one half of the production and maintenance employees in our estimates of the population at risk.

Recent (1975) fiber concentrations measured in the primary asbestos manufacturing industry have been reported in the Asbestos Information Association-Weston submission to OSHA as a response to the October 1975 proposed revision to the asbestos standard [Daly et al, 1976]. These data indicate the following asbestos concentrations were present in the respective industry segments:

Primary industry	1975 asbestos fiber concentrations (f/ml)	
	Range	"Typical"
Asbestos paper	0.10– 2.8	0.75–1.9
Asbestos cement pipe	0.25– 4.5	0.50–2.2
Floor tile	0.25– 4.3	0.50–1.75
Friction products	0.10–22.0	1.00–3.3
Paints, coatings, and sealants	0.25– 8.0	1.00–2.5
Asbestos cement sheet	0.25– 8.7	1.00–3.0
Gaskets and packing	0.10– 2.5	—
Reinforced plastics	0.20– 3.0	0.75–2.0
Asbestos textiles	0.25–15.0	1.00–4.0

Secondary manufacturing. Secondary industries are those that receive products containing asbestos and further process, modify, or fabricate them to produce other intermediate or final products. The following industries involve such processes:

Heating equipment except electric and warm air furnaces (SIC 3433). This industry is engaged in the production of heating boilers; domestic furnaces and gas burners; and oil burners, space, and wall heaters, all of which tended to incorporate asbestos insulation in their construction. We have included one half of the production and maintenance employees in our estimates of the population at risk.

Fabricated plate workers (Boiler Shops) (SIC 3443). Establishments in this industry are engaged in manufacturing power and marine boilers, pressure and nonpressure tanks, processing and storage tanks, and heat exchangers and similar products, many of which include asbestos insulation. The subdivisions of this industry that utilize extensive asbestos insulation (heat exchangers and steam condensers; steel power boilers, parts and attachments; and nuclear reactor steam supply systems) accounted for approximately one half of the industry's total production workers in 1977. We have included one half of the production and maintenance employees in our estimates of the population at risk.

Industrial process furnaces and ovens (SIC 3567). This industry produces industrial process furnaces, ovens, induction and dielectric heating equipment, and related devices. All of the subdivisions make extensive use of asbestos insulation and all of the production and maintenance employees are included in our population at risk estimates.

Electric housewares and fans (SIC 3634). Establishments in this industry are engaged in manufacturing electric housewares for heating, cooking, and other purposes and electric fans. We estimate that 10% of the production and maintenance employees are at risk of asbestos-related disease.

Asbestos is used in a variety of other secondary industries. These include friction products, reinforced plastics, products containing asbestos paper, various industries manufacturing laboratory equipment, electrical switchboards, cooling tower components, fire protection materials, etc. It is impossible to extract the number of individuals in all secondary manufacturing from BLS data. The only published information is that from the Weston analysis done in cooperation with the asbestos industry [Daly et al, 1976]. They report the following 1975 employment data for secondary manufacturing industries, categorized by the primary source of asbestos:

Primary source of asbestos materials	Number of exposed employees
Asbestos paper	158,400
Friction products	27,600
Asbestos cement sheets	19,200
Gaskets and packings	12,000
Reinforced plastics	8,400
Asbestos textiles	6,000
Miscellaneous	8,400
Total	240,000

By comparison, our estimate of the asbestos-exposed employment during 1975 for the four industries listed previously (SIC 3433, 3443, 3567, and 3634) totaled 38,000. Moreover, only employees of companies manufacturing electric housewares and fans would appear to have been included in the Weston tabulations. However, it is difficult to be certain that their classification of primary and secondary is similar to ours. In their classification, they estimate 23,000 to be exposed in primary manufacturing in 1975 versus our estimate of 31,000.

Thus, some of our primary industry may be their secondary. It is difficult to estimate the exposures the individuals identified by Weston would have had. Some data are presented on current asbestos concentrations (see below). It is unlikely, however, that 158,000 employees would have had significant exposures during the manufacture of products containing asbestos paper. The data in the other manufacturing segments appear reasonable, however. To account for all these exposures, we will consider that a number equal to twice the four groups specified by SIC numbers are additionally exposed in secondary manufacturing. (This additional number totals 76,000 in 1975.)

Data provided by Asbestos Information Association-Weston on fiber counts in secondary manufacturing are:

Secondary industry[a]	Asbestos fiber concentration range reported (f/ml)
Asbestos paper	1.0–3.5
Friction products[b]	2.5–6.5
Asbestos cement sheet	1.0–6.0
Gasket and packing	0.2–5.0
Asbestos-reinforced plastic	0.5–2.0
Asbestos textiles	0.5–5.0

[a]Categorized by primary source of asbestos material.
[b]Does not include brake and clutch maintenance.

No information is available on dust counts in these industries in earlier years.

Shipbuilding and repair (SIC 3731). The risk of asbestos-related disease among shipyard workers was emphasized in 1968 by Harries, who reported five cases of pleural mesothelioma among employees of the Royal Navy Dockyard in Devonport [Harries, 1968]. His findings were noteworthy in that none of the patients was an "asbestos worker." They were employed in other trades (boilermaker, shipwright, laborer, welder, fitter) and worked in shipyards with asbestos workers but did not themselves often use asbestos. In addition, cases of asbestosis were noted. Stumphius described similar findings in the Netherlands [Stumphius, 1968]. Again, the mesotheliomas were among workers other than those in the usual asbestos trades. Since these initial communications, experiences have been detailed in many parts of the world identifying characteristic asbestos-associated disease among former shipyard workers, including pleural mesothelioma, peritoneal mesothelioma, asbestosis, and lung cancer. Evidence of asbestos-associated disease has been reported among workers employed in United States shipyards during and after World War II [Department of Health, Education, and Welfare, 1981; Felton, 1979; Selikoff, 1965]. These findings indicate that the nature of shipyard work during this period provided significant opportunity for exposure to asbestos of the many trades employed, even though such exposure might have been only intermittent or indirect.

We have included all production and maintenance employees of private and naval shipyards in our estimates of the population at risk. The estimates for naval shipyards, however, are taken from the United States Department of the Navy [Nunneley, Department of the Navy (Personal Communication, 1980)].

Construction. The construction industry accounts for an estimated 70%–80% of total United States consumption of asbestos fiber [Levine, 1978]. Substantial direct exposure to asbestos occurs in the following subdivisions:

1. General contractors—residential buildings other than single family (SIC 1522).
2. General building contractors—nonresidential buildings (SIC 154).
3. Water, sewer, pipe line, communication, and power line construction (SIC 1623).
4. Construction—special trade contractors (SIC 17, except 1771 [concrete work], 1781 [water well drilling], 1791 [structural steel erection], 1794 [excavating and foundation work], 1796 [installation or erection of building equipment, not elsewhere classified]).

Among the asbestos products involved in direct exposures in construction work are asbestos-cement pipe installation; asbestos-cement sheet installation; architectural panel installation; built-up roofing installation; drywall removal, replacement, and installation; removing of roofing felts; asbestos insulation of pipe, tubing, heating units, and electric power generation equipment; paints, coatings, and sealants. In addition to the direct exposure resulting from the use of the above products, construction workers have been subject to considerable indirect exposure to asbestos as a result of the practice of spraying asbestos insulation in multistoried structures during the period 1958–1972. An investigation of the spraying of mineral fiber insulation material in New York City collected on-site samples taken at various distances from the spraying nozzle. It showed fiber counts ranging from 70 f/ml 10 feet from the nozzle to 3 f/ml 25 feet away [Reitze et al, 1972]. Workers in occupations not directly involved in spraying (carpenters, electricians, pipefitters, plumbers, welders, and others) who were on construction sites during or after such spraying are at risk to asbestos-associated disease.

We have included all construction workers in SIC 1522 and 154 in our estimates of the population at risk and the following proportions of the workers in other construction subdivisions:

SIC 1623. Thirty percent of the water distribution pipe sold in the United States in 1974 was asbestos cement [Meylan et al, 1978]. We assumed that this proportion of the workers in the water, sewer, etc, line construction industry is exposed to asbestos from asbestos-cement pipe. In addition, we included maintenance mechanics and helpers employed in SIC 16 (construction other than building construction) to reflect the fact that these workers are exposed to asbestos during the repair of brakes on heavy construction equipment [Hill, 1980]. These workers comprise approximately 5% of the total number of construction workers in SIC 16 [Bureau of Labor Statistics, unpublished].

SIC 17. We have included all construction workers in 171 (plumbing, heating [except electrical], and air conditioning) and SIC 172 (painting, paperhanging, and decorating) in our estimates of the population at risk. The former group has extensive exposure to asbestos in pipe covering and insulation for heating and ventilation equip-

ment. A mortality study of the members of the union of plumbers and pipefitters in the United States noted their potential exposures to asbestos and found significant excesses in proportional mortality ratios for malignant neoplasms of the esophagus, respiratory system, lung, bronchus, and trachea, and "other sites." [Kaminski et al, 1980]. Seven deaths were due to mesothelioma, a clear indicator of asbestos-associated disease.

The latter group (painting, paperhanging, and decorating) has been exposed to many asbestos-containing materials, including spackle compounds used by general painters, taping and joint compounds used in drywall construction, and additions of asbestos to sealant compounds or surfacing materials. Moreover, these workers have indirect exposure to asbestos materials used by other trades in the construction industry. A study of drywall taping workers employed in the New York metropolitan area found mean asbestos fiber concentrations ranging from 5.3 f/ml in hand-sanding to 47.2 f/ml in dry mixing operations [Fischbein et al, 1979]. Other researchers report mean fiber concentrations of from 0.9 to 19.6 f/ml during various activities of drywall taping [Verma and Middleton, 1980]. In addition to the tapers and painters directly engaged in these operations, members of all the construction trades working in the vicinity of ongoing drywall construction were significantly exposed. Mean fiber concentrations varying from 2.3 to 8.6 f/ml were observed at distances from 3 to 20 feet from the taping operation in the same room. In adjacent rooms, background mean fiber levels varied from 2.6 to 4.8 f/ml at distances from 15 to 25 feet from the taping operations.

For the remaining groups covered by SIC 17 (except the five groups identified under 4 above as not being substantially exposed), we have estimated that the proportion of the construction workers at risk during 1958–1972 was 50% (when multi-storied buildings were sprayed with asbestos fireproofing material) and 20% during 1940–1957 and 1973–1979. The following proportions of these groups were found to be exposed to asbestos in the National Occupational Hazard Survey [National Institute for Occupational Safety and Health, unpublished]:

SIC code	SIC description	% Employees exposed to asbestos
173	Electrical work	15
174	Masonry, stonework, tilesetting, and plastering	27
175	Carpentering and flooring	15
176	Roofing and sheetmetal work	41
1793	Glass and glazing work	40
1795	Wrecking and demolition work	NR
1799	Special trade contractors, not elsewhere classified	23

NR, Not reported.

It should be noted that the above percentages understate the proportions of "construction workers" exposed to asbestos in these industries since they are based on the total employment reported rather than total construction workers; the latter concept excludes executive and managerial personnel, professional and technical employees, and routine office workers [Bureau of Labor Statistics, 1976].

Electric, gas, and combination utility services (SIC 491, 492, 493). Power generating facilities have many work areas with elevated temperatures, which have been insulated with asbestos-containing materials, including preformed blocks of hydrous calcium silicate insulation reinforced with asbestos fibers. Other insulation used in this industry consists of asbestos boards, blankets, felts, cloths, tapes, sleeves, and cements that contained various quantities of asbestos [Fontaine and Trayer, 1975]. Studies conducted in England [Bonnell et al, 1975] and France [Fontaine and Trayer, 1975] have found substantial evidence of asbestos-associated disease among persons engaged in maintenance work at power stations, including persons not directly involved in applying or removing insulation materials. We have included one quarter of the "physical workers" employed in electric and gas utilities in our estimate of the population at risk: 10% representing maintenance workers and 15% other persons in the area who are indirectly exposed [H. Jones, 1980].

Occupational groups. The industrial activities for which employment statistics are gathered do not correlate closely with those in which there is occupational contact with asbestos. It has been necessary, therefore, to supplement the estimates derived from the above analysis of industrial employment statistics with estimates of the number of persons employed in particular occupations (crossing industry lines) where significant asbestos exposure has occurred. We have reduced the industry estimates of persons at risk by the numbers employed in the selected occupations to avoid double-counting. The following occupational groups were defined as at risk:

Asbestos and insulation workers. A strikingly increased death rate of lung and other cancers has been observed among a group of asbestos and insulation workers [Selikoff et al, 1979]. All such individuals have significant risk.

Data are available from three research groups on average fiber concentrations in insulation work prior to 1970, when the techniques of application and control measures used were typical of the industry during previous years [Balzer and Cooper, 1968; Ferris et al, 1971; Murphy et al, 1971; Nicholson, 1975]. The data are presented in terms of time (and job-weighted) average concentrations. During certain operations (cement mixing, hand- or band-saw cutting, removal), extremely high concentrations were observed (up to 100 f/ml). However, these operations constituted only a small fraction of the insulators' work activity. Data were also estimated for earlier years when the asbestos content of insulation was twice that of 1965–1970.

Summary of Average Asbestos Air Concentrations During Insulation Work

	Average fiber concentration (f/ml)	
Research group	Light and heavy construction	Marine work
Average concentrations of fibers longer than five micrometers evaluated by membrane filter techniques and phase-contrast microscopy		
Reitze-Nicholson, Mount Sinai [Nicholson, 1975]	6.3	
Balzer-Cooper, U. of Calif. [Balzer and Cooper, 1968]	2.7	6.6
Burgess-Lynch, Harvard [Ferris et al, 1971]		2.9

Average concentrations of all visible fibers counted with a konimeter and bright-field microscopy	
Murphy, Harvard [Murphy et al, 1971]	8.0
Fleischer, US Navy [Fleisher et al, 1946]	30–40
Estimates of past exposure based on current membrane filter data	
Nicholson, Mount Sinai [Nicholson, 1975]	10–15

Automobile body repairers and mechanics. A study of brake-lining maintenance and repair work has found short-term concentrations of asbestos of 16.0, 3.3, and 2.6 f/ml at distances of 3–5 feet, 5–10 feet, and 10–20 feet, respectively, from a worker blowing dust out of automotive brake drums [Rohl et al, 1976]. Grinding truck brake-shoes gave an average concentration of four f/ml and bevelling produced an average count of 37 f/ml. Measurable concentrations (0.1 f/ml) were found at distances up to 75 feet from the blowing-out operation (14 minutes after), 60 feet from grinding and 30 feet from bevelling, indicating that other garage employees besides those directly involved in brake and clutch repair are at risk.

Average fiber concentrations during brake and clutch work, however, are much lower and average about 0.1–0.3 f/ml during the course of an entire brake repair job. These data and the sources are:

Summary of Asbestos Concentrations During Automobile and Truck Brake Maintenance Activities: Long-Term Samples During Lining Removal and Replacement

Source	Range of all concentrations measured (f/ml)	Range of garage mean concentrations (f/ml)
Personal		
NIOSH [R. Zumwalde, personal communication] Sampling may have been done during non-brake work. No information on work practices.	0.01–3.24	0.03–0.59
Hickish and Knight [1970] Appears typical of past work practices with air blowing of drums. Sampling throughout complete brake repair job.	0.08–7.09	0.68–3.1
Raybestos-Manhattan [J. Marsh, personal communication] Well-controlled exhaust ventilation utilized.	0.02–0.4	0.05–0.1

	Area	
NIOSH [R. Zumwalde, personal communication]	0.01–1.72	0.1 –0.57
Hickish and Knight [1970]	0.07–0.28	0.15

Initial clinical surveys of garage mechanics indicate that they have a small excess prevalence of X-ray abnormalities (~ 5%) compared with blue-collar control groups, in agreement with the dust count information above [Nicholson, 1982].

Engine room personnel, seagoing vessels, United States Merchant Marine. The potential for exposure to asbestos insulation material on merchant ships is not confined to the shipyards where the ships are built or repaired. After the vessels have been put to sea, flaking and cracking of the asbestos insulating materials covering machinery casings, steam and hot water piping, and tanks are common. In the course of a voyage, crewmen make repairs on pipes, pipe flanges, or valve leaks. This generally requires tearing down the insulation materials and replacing them [Polland, unpublished]. A study of 6,671 X-ray films of marine engineers in the United States showed an unusually high proportion (16%–20%) of pleural abnormalities, indicating the adverse effects of inhaled asbestos. [R.N. Jones, 1980]. We have included all engine room personnel on seagoing vessels of the Merchant Marine in our estimates of the population at risk.

Maintenance employees: Chemicals and petroleum manufacturing. The manufacturing processes of chemical production and petroleum refining involve the use of extensive networks of pipes, boilers, and other high temperature equipment. Asbestos materials provide thermal insulation for these networks and a large force of maintenance workers is employed to maintain and repair the production equipment. A study of maintenance workers in a large chemical plant and an oil refinery showed relatively frequent chest X-ray abnormalities [Lilis et al, 1980]. These findings strongly suggest that asbestos exposure characteristic of maintenance work in chemical plants and in oil refineries, including indirect ("bystander") exposure, results in risks comparable to those documented for other types of asbestos exposure in other industries and occupations. We have included all maintenance workers in the chemicals and allied products (SIC 28) and petroleum refining and coal products (SIC 29) in our estimates of the population at risk.

Steam locomotive repair. Employees engaged in the overhaul of railroad engines during the period when steam locomotives were in service were heavily exposed to asbestos. The practices used in the "back shops" where overhauls were conducted, resulted in the generation of clouds of asbestos dust that contaminated the environment of all who worked in the area [Mancuso, 1976]. Five mesotheliomas have recently been identified by NIOSH among former employees of one shop in Reading, Pennsylvania We included all employees of railroad repair back shops in our at-risk estimates for the decade of the 1940s (when steam locomotives were the predominant type). For the 1950s (when the proportion of all locomotives in service which were steam declined from 63.4% to 1.7%), we reduced the annual number of employees at-risk by the annual proportion of nonsteam locomotives to all locomotives.

Stationary engineers, stationary firemen, and power station operators. Operation and maintenance of stationary engines and mechanical equipment to provide utilities for buildings and industrial processes involve the same types of exposure to asbestos-containing materials as are described above under electric, gas, and combination utility services. A preliminary field survey of 34 stationary engineers by this labora-

tory in the New York metropolitan area has found X-ray abnormalities consistent with asbestos-induced changes in 60% of the employees with more than 20 years of experience in this trade. We have included all employees in this occupational group in our estimates of the population at risk.

Population Estimates

In estimating the mortality (or morbidity) from past exposure to asbestos, we would wish information on the number of individuals exposed; the distribution of their employment periods; the time, duration, and intensity of the asbestos concentrations to which they were exposed; and mortality data, by industry, correlated with the above variables. Unfortunately, we have little of the above data. There are limited data on the number of individuals exposed to asbestos in different calendar periods of time. For some industries data are good (primary asbestos manufacturing, shipbuilding, auto repair and, to a lesser extent, insulation work). Much less certain are data on exposed populations in construction, secondary manufacturing, and the maintenance industries. Least certain is information on the turnover in a given industrial segment. Exposure data are available in recent years, but generally only from a limited number of measurements in an industry. Extrapolations to earlier years are possible but necessarily uncertain. Of most use are current data on the mortality of entire population groups exposed in previous years. Such information, if related to exposure periods, eliminates our need for information on exposure distributions as the mortality data for an entire group includes all exposure circumstances.

Further, as will be demonstrated subsequently, several studies show that the risk of lung cancer is linearly related to the total fiber exposure. This information allows one to properly account for different durations of employment in a given industry. Moreover, for the purposes of estimating excess mortality, it also reduces our need for accurate information on work force turnover within an industrial segment. The excess mortality for 1,000 men exposed for ten years is the same as for 2,000 men exposed for five. The important parameter is the person-years-at-risk. Thus, information on the total work force exposed at various points in time is much more important than information on turnover. However, for consideration of surveillance activities, one would wish knowledge of the total population at risk. This can be estimated, but greater uncertainties exist in the values obtained than in the number of asbestos-related cancers that might develop.

Methodological Considerations

Considerable information is available from data published by the Bureau of Labor Statistics and from industry or union sources on the number of individuals employed in an industry at periods of time. Data from publications of the Department of Labor also provide some information on the number of individuals entering or leaving a given industry on a yearly and monthly basis. For some industries subsequent to 1958, this includes information on the fractional number of accessions and separations that occurred for given employees within a calendar period. Often data are provided on the total fractional number of new hires, recalls, layoffs, and quits. While the information on the fractional number of new hires is of use to us in estimating the population entering a given industry, it does not represent true new hires for our purposes. This is because the industry data are based on individual establishment experiences. A new hire for an establishment may be an individual who previously worked in another establish-

ment in the same industry. For some manufacturing industries, this may not be too great a duplication, but for construction trades particularly, it represents significant duplication.

To estimate the population at risk for a period of years, it would be most desirable to have information on the number of new employees entering a given occupation or industry at different points in time and information on the number of individuals currently leaving that occupation or industry permanently. If N = the number in an industry, α = the fractional number of new entrants in an occupation or industry in a given year (N_{new}/N_{tot}), and β = fractional number leaving an occupation or industry permanently, the change in an industry work force can be represented by $dN = N \times (\alpha - \beta)dt$.

For small changes in N, $N = N_0 e^{(\alpha - \beta)t}$. In this model, in the absence of new entrants into an industry, the work force will decrease with a half-life, $T_{0.5} = 0.693/\beta$. In the absence of any separations, it will increase with the doubling time, $T_2 = 0.693/\alpha$. In any steady-state or near-steady-state situation, where $\alpha = \beta$, the average duration of employment is equal to $1/\alpha$. When one considers finite changes over a year period of time, $\Delta N = (\alpha - \beta)N$, where ΔN is the net increase or decrease. Thus, $\alpha = \beta + (\Delta N/N)$. If we consider the time necessary to achieve complete replacement of a work force in a steady-state situation, $\Delta N = N = \alpha NT$. Thus T, the time necessary for work force replacement is equal to $1/\alpha$ as expected from the earlier consideration of continuous changes. As indicated previously, we will be using information on the number of new entrants into a trade or industry, coupled with their average period of employment, to generate estimates on the expected excess mortality from past exposure to asbestos. The excess mortality among a group of individuals entering an industry during a decade will be proportional to $\alpha N \times T$ (new hires $\times$ employment period) $= k\alpha N \times 1/\alpha = kN$, where k, the proportionality constant, includes the appropriate risk and exposure variables for the industry. *Thus, the crucial item in estimating mortality in a steady-state work situation is information on the number employed in an industry rather than the number of new hires entering it.* More detailed information is only necessary if there are significant changes in the workforce over the period of time being considered.

Asbestos-Exposed Work Force

The data on the population exposed to asbestos in different industries has been estimated using the Bureau of Labor Statistics information on employment and earnings in the United States, 1909–1978. Here direct data are available on the yearly employment in the following industries under consideration: primary asbestos manufacturing; selected secondary asbestos manufacturing industries; construction; electric, gas and utility services; and chemical and oil refining employees. The segments of these industries that will be considered at risk have been described previously.

We used employment series published by the Bureau of Labor Statistics [1979] as the basis for estimating the number of persons employed. Where the data do not extend as far back as 1940, we extrapolated the BLS series to that year on the basis of regression equations with related variables (Table II) or on the assumption of a straight-line trend between Census Bureau data for 1939 (Census of Manufacturers) or 1940 (Census of Population) and the earliest year of the relevant BLS series.

In the construction industry, the employment data relate to "construction workers." This group covers "workers up through the level of working supervisors, who are

engaged directly on the construction project either at the site or working in shops or yards at jobs ordinarily performed by members of construction trades. Exclusions from this category include executive and managerial personnel, professional and technical employees, and routine office workers" [Bureau of Labor Statistics, 1976].

In electric, gas, and combination utility services, the employment data relate to "physical workers." This group includes working foremen and other nonsupervisory workers engaged in nonoffice functions [Department of Labor, 1979].

In manufacturing industries (including private shipbuilding and repair), the employment data relate to "production workers." This group covers those employees, up through the level of working supervisors, who are engaged directly in the manufacture of the product. Among the exclusions from this category are persons in executive and managerial positions, those engaged in office work, and professional and technical functions [Bureau of Labor Statistics, 1976].

In the chemicals and allied products industry, it was estimated that 27% of the BLS employment figure represented maintenance workers. This proportion was calculated from the BLS Reports on 1971 occupational employment in this industry [Bureau of Labor Statistics, 1974]. The following classifications were excluded from the maintenance occupations to avoid duplication: insulation workers, stationary engineers, stationary boiler tenders.

In petroleum refining and coal products, it was estimated that 40% of the petroleum refining production employees and 20% of the production employees in the remaining divisions of the industry represented maintenance employees [Bureau of Labor Statistics, 1965]. The 1940 employment in the industry was estimated on the basis of a straight-line interpolation between the 1939 figure reported by the Bureau of the Census [1939], and the 1944 BLS figure. The same maintenance occupations were excluded as is noted under chemicals (above) to avoid duplication.

Data are not available that allow direct use of BLS employment data to estimate the number of individuals employed in insulation work, shipbuilding, automotive maintenance, merchant marine engine room work, and steam locomotive repair. Sepa-

TABLE II. BLS Employment Series Extrapolated to 1940 by Means of Regression Equations

Series to which extrapolation was applied	Related variable used for estimation	Measure of validity (r^2)
Construction—general building contractors: construction workers (SIC 15)	Construction—all employees 1964-1973 (SIC 15, 16, 17)	0.97
Construction—other than building general contractors: construction workers (SIC 16)	Construction—all employees 1960-1971 (SIC 15, 16, 17)	0.68
Construction—special trade contractors: construction workers (SIC 17)	Construction—all employees 1947-1956 (SIC 15, 16, 17)	0.99
Electric, gas, combined utilities employed	Production of utilities 1950-1959	0.84
Manufacturing: heating equipment excluding electrical: production workers	Manufacturing—fabricated structural metal products: production workers, 1972-1979	0.61

rate data are available in these industries from union sources, trade associations, the US Navy, and other government sources.

Insulation workers. For this important group of asbestos-exposed individuals, we will utilize information from the International Association of Heat and Frost Insulators and Asbestos Workers (IAHFIAW) to estimate the work force at any time and the new entrants into the trade [International Association of Heat and Frost Insulators and Asbestos Workers, unpublished; R. Steinfurth, personal communication]. The data available from the union are presented in Table III, which provides information on the cumulative entrants into the union, reduced by the number of Canadian members. Also available are data on the actual union membership in recent years and the number of new entrants and separations on an annual basis. For the years prior to 1960 where such data are uncertain, the estimates of Union membership were extrapolated from the trend available in the years 1960–1980. A small correction to the union membership is made for the estimated number of retired members over age 65. This correction is a small one because the high mortality in this trade limits the number who attain age 65.

The number of union construction insulation workers in Table III is increased by 40% for the years subsequent to World War II to account for workers employed on union jobs on a temporary (permit) basis and by an amount equal to the union membership to account for construction insulation workers not so represented. For the year 1940, few individuals would have been employed on permit because of the scarcity of jobs at that time. However, during World War II, a large number of insulators were so employed, particularly in shipyards. Data suggest that 0.2% of the wartime shipyard work force of 4,500,000 men and women were insulators. Thus 9,000 individuals would have been employed for approximately one year in this industry.

Unpublished data from the Bureau of Labor Statistics estimates that 31,900 men were at work during the spring of 1978 as insulation workers in construction and an additional 19,100 employed in industry elsewhere.[1] The 31,900 estimate from Bureau of Labor data is a reasonable agreement with the 38,900 estimate using union information as described above. Short-term layoffs during 1978 could well account for at least 10% of the work force. We will use the mean of the Bureau of Labor Statistics estimate and the estimate from union data as the value for construction insulation workers. This will decrease the values in Table III by 8.3%. The adjusted total number of construction insulators will then be increased by 54.4% (19,100/35,900) to account for insulators employed in maintenance elsewhere.

Shipbuilding and repair. BLS data awre available on civilian production shipyard workers. The number of employees in Naval shipyards was obtained from data of the US Navy [J.K. Nunneley, Department of the Navy, personal communication, April 22, 1980]. This information is listed in Table IV. While the Navy estimates that only 50% of the yard work force is exposed to asbestos, the data on mortality and morbidity that we will use estimates risk for all shipyard workers as a group. We will utilize, therefore, the percentage of civilian yard workers that are production employees for the Naval shipyard considered to be exposed to asbestos. (This ranges from 92% in 1950 to 80% in 1975). In estimating the shipyard employment for 1945, we have used a value of 175,000, which is intermediate between 1940 employment and that of the years subse-

[1]Based on the ratio of 1978 total employment reported by BLS (51,000) to the number employed in construction (31,948), an unpublished BLS estimate.

TABLE III. Insulator Work Force and New Hires Using Data From the International Association of Heat and Frost Insulators and Asbestos Workers*

Year	Cumulative new members (January)	Estimated union membership	Membership as a percentage of cumulative membership[a]	Estimated percentage of retired (>age 65)	Estimated percentage of Canadian membership	Estimated IAHFIAW active US membership	Estimated number of construction insulators
1940	9,100	6,280	69.0	2.5	0.0	6,120	12,250
1945	12,580	8,300	66.0	2.7	3.0	7,830	18,800
1950	16,360	10,310	63.0	3.0	3.1	9,690	23,260
1955	22,150	13,290	60.0	3.5	7.0	11,930	28,630
1960	26,800	15,750	58.7	4.0	8.0	13,910	33,380
1965	31,000	17,720	57.2	4.5	8.6	15,470	37,120
1967	32,700	17,800	54.4	4.9	9.9	15,250	36,610
1970	35,400	18,500	52.3	5.0	12.0	15,470	37,120
1975	41,000	19,800	48.3	5.5	14.0	16,090	38,620
1978	44,400	20,200	45.5	6.0	16.0	15,950	38,280
1980	46,600	20,000	42.9	6.0	16.6	15,680	37,630

*Source: Roy Steinfurth, Director, IAHFIAW Health Hazard Program (personal communication).
[a]Extrapolation from 1955 to 1940 was based on the trend of this parameter.

quent to World War II. We will consider this to be the "permanent" work force that would have been employed in the absence of World War II. During that conflict, it is estimated that an additional 4,325,000 men worked in shipyards for short periods of time [Selikoff and Hammond, 1978]. Their mortality and that of 9,000 wartime shipyard insulators will be estimated separately.

Automobile maintenance and repair. Mechanics exposed to asbestos during brake and clutch maintenance are included in SIC 75, auto repair, services and garages and SIC 515-2, new and used car dealers, and some in SIC 554, gasoline service stations. As it is not possible to separate mechanics from other employees in these categories, we have used census data of the number of individuals employed as mechanics in auto maintenance and auto body repair. Intercensus data were developed using a linear interpolation. See Table V for the basic data utilized.

Railroad steam locomotive repair. We have utilized employment data reported by the Association of American Railroads for occupations exposed to asbestos during the maintenance of steam railroad locomotives. This was done by reducing the number of men classified in equipment and stores [Association of American Railroads, annual] by 45% to reflect the proportion of the total craftsmen accounted for by the carmen classification. (Carmen were generally engaged in maintenance of railway cars rather

TABLE IV. Estimated Population at Work in United States Naval Shipyards, 1940–1979 (in thousands)*

Years	Employed at start of quinquenium	Estimated accessions during quinquenium
1940–1944	72	480
1945–1949	335	267
1950–1954	71	132
1955–1959	112	68
1960–1964	96	73
1965–1969	81	93
1970–1974	82	47
1975–1979	60	55

*Source: JK Nunneley, United States Department of the Navy (personal communication, April 22, 1980).

TABLE V. The Population Exposed to Asbestos in Automobile Maintenance and Repair

Year	Census[a] data (thousands)	Motor[b] vehicle registrations (millions)	Interpolated population at risk
1940	372	33	372
1945		32	370
1950	647	50	647
1955		63	655
1960	661	74	661
1965		92	800
1970	912	108	912
1975[c]		133	1,100

[a]Includes auto body repairmen.
[b]From Highway Statistics (annual) US Federal Highway Administration.
[c]Weston estimated that 900,000 workers were continuously exposed to asbestos in automobile brake repair and 1,070,000 were exposed occasionally or infrequently.